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Comparative Economic Analysis of Floating Photovoltaic Systems Using a Synthesis Approach

Ching-Feng Chen, Shih-Kai Chen

***Abstract*—**The Floating Photovoltaic (FPV) system highlights economic benefits and energy performance to carbon dioxide (CO_2) discharges. Due to land resource scarcity and many negligent water territories, such as reservoirs, dams, and lakes in Japan and Taiwan, both countries are actively developing FPV and responding to the pricing of the emissions trading systems (ETS). This paper performs a case study through a synthesis approach to compare the economic indicators between the FPVs of Taiwan's Agongdian Reservoir and Japan's Yamakura Dam. The research results show that the metrics of the system capacity, installation costs, bank interest rates, and ETS and Electricity Bills affect FPV operating gains. In the post-Feed-In-Tariff (FIT) phase, investing in FPV in Japan is more profitable than in Taiwan. The former's positive net present value (NPV), eminent internal rate of return (IRR) (11.6%), and benefit-cost ratio (BCR) above 1 (2.0) at the discount rate of 10% indicate that investing the FPV in Japan is more favorable than in Taiwan. In addition, the breakeven point is modest (about 61.3%). The presented methodology in the study helps investors evaluate schemes' pros and cons and determine whether a decision is beneficial while funding PV or FPV projects.

***Keywords*—**Carbon Border Adjustment Mechanism, Floating Photovoltaic, Emissions Trading Systems, Net Present Value, NPV, Internal Rate of Return, IRR, Benefit-Cost Ratio.

I. Introduction

CLIMATE change enormously challenges global economic development and the environment. UN's Intergovernmental Panel on Climate Change (IPCC) emphasizes the importance of implementing carbon prices to mitigate the rise in global mean temperature and achieve the goal of limiting it to 2 °C, in alignment with the Paris Agreement. 61 countries, cities, states, and provinces already utilize carbon pricing mechanisms, covering 12 trillion tons (Gt) of carbon dioxide equivalent (CO_2e), about 22% of global greenhouse gas (GHG) emissions. Carbon pricing programs contain about 50%, i.e., approximately 13% of annual GHG discharge. They help mitigate the damage to those responsible for reducing it. Introducing carbon pricing proposes a benchmark based on an economical cost, allowing polluters to decide whether to stop their polluting activities and reduce emissions or continue to pollute and pay a carbon price to achieve overall environmental goals [1].

Recently, some countries have gradually incorporated GHG-related indicators into international voluntary green labels or product verifications. Well-known titles are such as the German Blue Angel Mark, the American Electronic Product Environmental Impact Assessment Tool (EPEAT), the Malaysian Official Green Product Certification (MyHIJAU MARK), and the French Sun [2].

World Bank (2022) [1] elaborated that ETS and carbon taxes are the two primary types in its pricing-carbon report. ETS refers to a cap-and-trade system. It caps the overall GHG outflows and approbates those manufacturing with low release to sell their additional allowances to more gross emitters. It creates the supply and demand for exhalation allowances and establishes the market price for GHG emanations. In addition, it helps ensure that the required ejection declines and mandates emitters' carbon emissions within their carbon budgets. A carbon tax, unlike ETS, is not a pre-defined outflow reduction outcome but directly sets a tax rate on GHG emissions or the carbon content of fossil fuels. Emitters must compensate for discharges through ETS or a carbon tax. Consequently, carbon prices drive clean and low-carbon energy innovations.

The International Monetary Fund (IMF) investigation indicates that the global average carbon price is over 50% below US$10 per metric ton. It claims carbon prices must reach $50 to $100 by 2030 to comply with the Paris agreement. The ETS prices in Switzerland and Portugal, Europe, have increased from US$5 in 2019 to US$19 and US$14 to US$26.

South Korea in Asia has raised the price per unit of carbon credit from US$22 in 2019 to the current US$33 [3].

In previous studies, Trapani and Santafé examined the economic feasibility of using existing water bodies to increase the installation of solar projects. They claimed that some significantly advanced countries such as Japan, France, the United States, Germany, the United Kingdom, and Canada have actively invested in this field due to their economic feasibility [4].

Billinton and Allan used mathematical equations to randomly evaluate the gains of the constructed projects under the assumptions of the collected data but not the actual operation of the system [5]. The research results on the FPV and hydropower cooperative process in Brazil's Sao Francisco River Basin show that the optimal local installation angle, 3°, generates enormous energy and the lowest power generation cost, ranging from 0.052/kWh to 0.055/kWh [6].

Goswami and Sadhu [7] declared that the electricity cost of the FPV station is only US$ 0.026/kWh. It is 39% lower than the onshore PV power stations after investigating the technical and financial feasibility of the conventional ground-based PV and FPV systems for the 10 MegaWatt peak (MWp) FPV project at Neel-Nirjan Dam, India. They asserted that the FTV station increases power generation by 10.2%, saves about 92.9

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kilotons (kt) of coal, and reduces about 340.8 kt of CO_2. The study compared the pros and cons of various onshore and offshore FPV stations and recommends installing FPVs to subtract electricity costs and protect the environment. After reviewing 30 FPV deployments installed and put into operation worldwide, they concluded that the payback period (PP) of FPV investment is approximately five years [5].

Although many studies have mentioned the pros and cons of FPV, most focus on competing for the cost and photoelectric conversion efficiency with land-based photovoltaic (PV) stations, reducing water evaporation and improving water quality [8]-[10]. Little literature archives the contrast of the economic benefits of different installation sites. Less mention of carbon trading could inject potential gains into FPV investments.

This paper conducts a comparative economic analysis between the FPVs of Taiwan's Agongdian Reservoir and Japan's Yamakura Dam using an integrating method to complement the inadequacies of this research field. By analyzing and comparing the economic indicators of the FPV schemes between the two sites, the case study presented in this paper will facilitate the assessment of the substitute scheme and benefit investors in evaluating and determining which plan is favorable while investing.

II. PV System Category and FPV Framework

A. PV System Category

The academic community commonly classifies PV stations into ground-based and water-based ones based on installation sites. The former usually installs the system on a building or a non-building arena. In contrast, installers often utilize abandoned mines, ponds, reservoirs, and lakes to implement water-based PV projects [8], dividing the deployment into four categories: ground-mounted, roof-mounted, BIPV, and BAPV (Fig. 1).

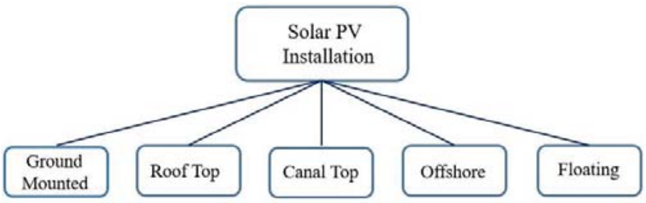

Fig. 1 PV System Type [8]

B. PV System Deployment

The FPV system is usually installed on a pontoon made of plastic and galvanized steel or completely plastic units. It has five divisions: a floating platform, a supporting structure, an anchoring system, underwater cables, and a solar PV system (Fig. 2) [9].

C. Single Diode Model of PV Module

The model illustrated in Fig. 3 describes the PV cell as a constant function for operating conditions and electrical parameters. It includes a current source, diode, shunt, and series resistor connected to the load [10].

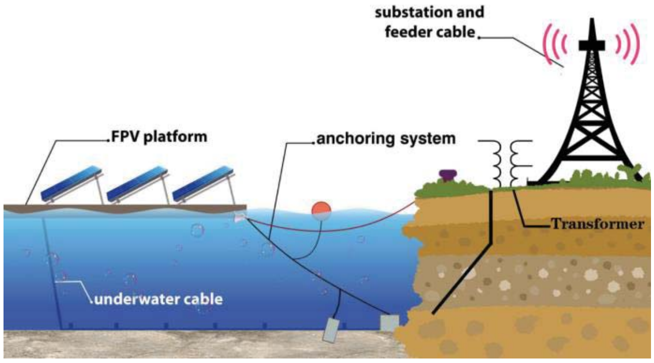

Fig. 2 FPV Framework [9]

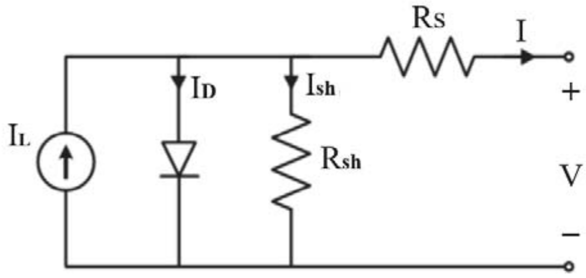

Fig. 3 PV Cell's Equivalent Circuit (i.e., SDM) [10]

Equation (1) expresses the load current (I_L) for SDM [11], [12]:

$$I_L = I_{pc} - I_{rsc}[\exp(\frac{V_0+I_L R_S}{nV_{jv}})-1] - \frac{V_0+I_L R_S}{R_{sh}} \quad (1)$$

I_{pc} indicates the photoelectric current, I_{rsc} to the reverse saturation current, V_o to the cell output voltage, R_s to the series resistance, n to the diode ideality factor, V_{jv} to the junction voltage, and R_{sr} to the shunt resistance.

In (1), I_L, I_{rsc}, R_s, α, and R_{sh} are unknown. To evaluate these parameters, manufacturers need to use Standard Test Conditions (STC), i.e., an irradiance of 1000 W/m^2 (AM1.5) and 25 °C to test the electrical parameters of the test conditions to achieve the module's parameters.

Under tropical conditions, the average solar cell P-N junction temperature remains below 12 °C due to installing the modules on the sea (water) surface or clarity. It improves the module's conversion efficiency by about 11% [13].

III. Case Study

A. Background

Due to Japan and Taiwan's lack of land resources, FPV hardly needs to use land and can fully use negligent waters. It requires delivering emphasis on the FPV development.

Benefiting from the promotion plan and learning from the development experience of the Yamakura FPV, Agongdian Reservoir FPV, as the most extensive onshore FPV in Taiwan, has contributed to Taiwan's FPV development as the first successful system among the installed projects. It has a 10 MWp (31,746 solar modules; 315 Wp per unit) installation capacity and exploits a water surface domain of 150,000 square meters. It began to supply power in March 2019 and produces an estimated annual power generation capacity of 12,000 MWh [14], [15].

In reservoir FPV, the largest FPV in Japan is Yamakura Dam in Chiba Prefecture. Its installation capacity reaches 13.74 MWp (50,904 solar modules; 270 Wp per unit) and utilizes 180,000 square meters of water surface area. It was connected to the grid in March 2018 and generated an estimated annual power of 16,170 MWh [16], [17]. Because of the similarity in land and energy shortages, compatibility of the installed modules' span, and export-dependent economies, the two countries are concerned with FPV development. Both must deal with the context of carbon trading taxes imposed when exporting to foreign countries, such as the European Union and the United States [18]. Consequently, it provides a potential benefit for clean energy industries.

B. Study Area

The Agongdian Reservoir, located at the junction of the Yanchao District and Tianliao District in the Lugangshan District, East Xiaogang Mountain, Kaohsiung City, is mainly used for flood control and farmland irrigation and managed by the Southern Water Resources Bureau of the Ministry of Water Resources. It covers an area of 31.87 square kilometers, with about 410 hectares that can reach the whole water level (Fig. 4). The total number of households in the Gangshan District is 35,145 (about 97,000 people) [14].

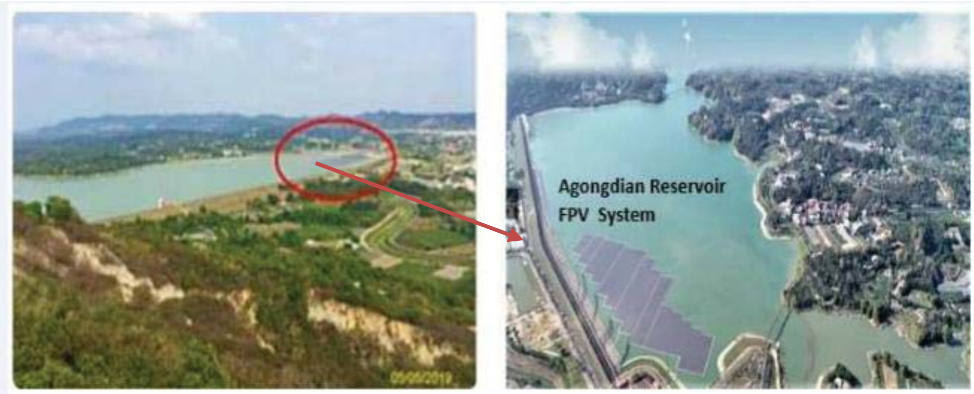

Fig. 4 Agongdian Reservoir FPV System (10 MWp) [15]

Yamakura Dam, built in 1964, is to provide local industrial water. The water storage area is about 61 hectares (Fig. 5). The investor installed solar modules on its 18 hectares, with an estimated annual power generation capacity of 15,636 MWh. It is Japan's most extensive floating solar power system and can approximately furnish electricity for 4,700 local households [16].

Fig. 5 Yamakura Dam Reservoir FPV System (13.7MWp) [17]

C. Financial Indicators

1. Net Present Value

NPV is the investment's future cash flow, which is all discounted into the value of the initial investment date. Assuming that the NPV of the asset is positive, the investment's result can increase the enterprise's value. Conversely, if the NPV of the investment evaluation is negative, this investment will reduce the value of the enterprise and should not be accepted [18].

Researchers can use (2) to determine the cost (negative cash flow) and benefit (positive cash flow) during each investment period (in years) [18].

$$\mathrm{NPV} = \sum_{t=0}^{N} \mathrm{N_t} \times (1+\mathrm{i})^{-\mathrm{t}} \quad (2)$$

where N: evaluation periods; t: construction and operation period; N_t = Net Cash Flow in year t; i = discount rate.

2. Internal Rate of Return

IRR is the number at which the discounted NPV value is zero. Therefore, researchers can use (3) to find IRR. It is an investment evaluation method that measures the return on investment without considering external factors such as various financial risks [19].

$$\mathrm{NPV} = \sum_{t=0}^{N} \mathrm{N_t} \times (1+\mathrm{i})^{-\mathrm{t}} = 0 \quad (3)$$

where N: evaluation periods; t: construction and operation period; Nt: Net Cash Flow in year t; i: discount rate.

3. Benefit-Cost Ratio

The BCR is usually used as a cost-benefit analysis indicator to express benefits and costs in the discounted present value. It can determine the matter by the discounted value of incremental benefits and total costs [20]—the higher the BCR, the better the return on investment. The project is an excellent investment if BCR is more significant than 1. On the contrary, if BCR < 1, the project cannot be profitable. Equation (1) shows how to find BCR. Equation (4) shows how to achieve the BCR [21]:

$$\mathrm{BCR} = \sum_{t=1}^{N} \mathrm{B}_{\mathbf{t}} \text{ x } (1+\mathrm{i})^{-\mathrm{t}} \,/\, \sum_{t=1}^{N} \mathrm{C}_{\mathbf{t}} \text{ x } (1+\mathrm{i})^{-\mathrm{t}} \quad (4)$$

N: evaluation periods; t: operation period (cash flow occurs); B_t to the cash flow (benefits) of period t. C_t to t: the cash flow (costs) of period t; i to the discount rate.

4. Payback Period

Scholars define the PBP as the years to recover the original cash investment [20]. It calculates from the start year of the investment by calculating net cash flow for each year expressed as (5) and (6):

The first net cash flow year = The first cash inflow year – The first cash flow outflow year (5)

Then,

Accumulative cash flow = The first net cash flow year + The second net cash flow year + …+ The n Net cash flow year (6)

The PBP is the year that the cumulative cash flow is positive.

5. Electricity Carbon Emission Coefficient

The ECEC shows GHG emission control status. Taiwan has set targets to regulate ECEC in stages since 2005. Its figure was 0.502 kg CO_2e/kWh in 2020 [22], which decreased by 4.5% compared to 2018. It combines the number into sales based on direct supply or transfer of public electricity or renewable energy. Therefore, ECEC has shown a downward trend since 2017 (Fig. 6) [23]. In Japan, affected by the policy of suspending nuclear power after the Fukushima nuclear disaster, the ECEC in 2020 reached 0.538 kg CO_2e/kWh [24].

Fig. 6 Graph of carbon emission coefficient of electricity over the years [23]

Equation (7) estimates the CO_2 volume emitted per kilowatt of electricity by dividing the fuel consumed by Taipower, private power plants, and cogeneration industries by the total power generation according to the Electricity Industry Law on ECEC description [25].

$$\mathrm{ECEC} = (CO_{2tpc} - CO_{2el}) \text{x } CO_{2t}^{-1} \quad (7)$$

CO_{2tpc} indicates the power generation industry, and self-use power generation installers sell electricity carbon emissions from public electricity sales, CO_{2el} to the electricity carbon emissions borne by the loss, and CO_{2t} to the total electricity sales of public electricity sales.

6. Operating Revenue and Gross Profit

Equation (8) expresses the relationship between yearly operating revenue and the factors of effective solar radiation time, system efficiency module attenuation, and system maintenance. Equation (9) delivers 25 years of CO_2 emission reduction [26]. Researchers can use them to obtain the benefits accordingly.

$$R_{op} \equiv C_{ins} \text{ (kWp/h) x } G_{effh} \text{ (h/day) x 365.25 (days/year) x 25 years x } S_{eff} \text{ x } (1+n) \text{ x } (1-D_{ar}) \text{ x } (1-M_{dt}) \text{ x } P_{hep} \quad (8)$$

$$V_{era} \equiv \mathbf{R_{op}} \text{ x } F_{ecec} \quad (9)$$

where $\mathbf{R_{op}}$: Yearly operating revenue; $\mathbf{C_{ins}}$: Solar module installation capacity (kWp/h); $\mathbf{G_{effh}}$: Effective daily electricity generation hours; $\mathbf{S_{eff}}$: System efficiency. This study uses 75% as the basis for calculation; n: The diode ideality factor; $\mathbf{D_{ar}}$: Decay rate of solar modules: yearly decrease by 1% [27]; $\mathbf{M_{dt}}$: System downtime time (5%): It depends on management and other climatic factors, such as typhoons and earthquakes; $\mathbf{P_{hep}}$: Average household electricity price; $\mathbf{V_{era}}$: Yearly CO_2 emission reduction amount (kg); $\mathbf{F_{ecec}}$: ECEC.

Equation (10) shows how to achieve the annual average operating margin. It expresses the yearly investment profit for which investors have not yet paid the corporate tax.

$$P_{gp} = R_{aor} - E_{aoe} \quad (10)$$

where P_{gp} represents the yearly gross revenue; R_{aor}: Annual operating revenue; E_{aoe}: Annual operating expenses.

7. Capital Recovery Factor (CRF) and Weighted Average Cost of Capital (WACC)

The CRF is the ratio that determines the constant annuity to the present value of achieving that annuity over a regular interval, such as monthly, quarterly, or yearly. Researchers must multiply the CRF factor (F_{crf}) by (11) to calculate an equal annual cash present value.

$$F_{crf} = i \times (1+i)^n \times ((1+i)^n-1)^{-1} = i \times (1-(1+i)^{-n})^{-1} \quad (11)$$

i indicates the appropriate discount rate, *n* to the project lifetime. To calculate the project's return, WACC is a more applicable discount rate [28].

Determining a plan's WACC is crucial as it is the discount rate that a company uses to estimate its NPV. A lower WACC indicates that a business can attract investors at a lower cost. In contrast, a higher WACC implies compensating investors with higher returns. As most companies (programs) yield capital from debt and equity, to express the company cost in a single figure, one has to weigh the costs of debt and equity proportionally based on how much they acquire financing through each source [29].

Equation (12) expresses the relationship between the F_{crf} and WACC [30]:

$$F_{crf} = WACC \times (1+WACC)^n \times ((1+WACC)^n-1)^{-1} = WACC \times (1-(1+WACC)^{-n})^{-1} \quad (12)$$

where

$$WACC\ (= R_{ir} \times L_{lr} + R_{oc} \times C_{ocr}) = R_{ir} \times L_{lr} + (R_{ir} + \beta) \times C_{ocr} = (R_{rf} + \alpha) \times L_{lr} + (R_{rf} + \alpha + \beta) \times C_{ocr} \quad (13)$$

n: Bulk purchase period; R_{ir}: Bank interest rate; L_{lr}: The loan ratio of the investment; R_{oc}: Return on own capital; C_{ocr}: The investment ratio of own capital; β: The risk premium; R_{rf}: The risk-free interest rate; α: An overweight for credit risk.

$$L_{lr} + C_{ocr} = 1$$

D.Methodology

This paper performs a case study to an economic analysis by comparing the FPV's financial and energy returns through a holistic approach at Taiwan's Agongdian Reservoir and Japan's Yamakura Dam. For this, we compared the two-site multiple economic indicators described in Section III *C*. It executes comparative economic analyses of a 10 MWp installed capacity to select a better scheme. The specific steps are as follows:

(1) Evaluate a set of predetermined metrics that may affect the FPV benefits based on factors' attributes.
(2) Perform supermatrix computations to make the pairwise comparison between variables to achieve each metric weight (the interdependence between the elements).
(3) Examine the Inconsistency Index (InCI) to determine if the InCl value is consistent with the criterion, which is less than or equal to 0.1, to determine the consistency of the pairwise comparison matrix within an appropriate range.
(4) Employ ELEC trend analysis to predict the CO_2 reduction effect and the FPV project financial benefits.
(5) Prepare and juxtapose the yearly concise accounting statement and financial indicators as a comparable base. Then, make a comparison.

E. Results

1. Predetermined Metrics and Supermatrix Computations

The research results show that the metrics of the system capacity, installation costs, bank interest rates, electricity bills, and ETS affect FPV operating gains. The last factor has the most significant impact, and the interest factor has a minor clash. It implies that contractors wanting to fund an FPV may consider loaning from banks to scale up the system and achieve more profits if the electricity bill remains or is even higher than the current bill.

2 Inconsistency Test and Relative Weights of the Metrics

Table I shows the InCI value of the FPV benefits and each metric's relative weight by comparing factors. The most weighted metric is ETS and Electricity Bills, and the least weighted metric is bank interest rates. As the InCI is equal to or less than 0.1, logical errors do not exist between the metrics [31]-[33].

TABLE I
INCI OF FPV BENEFIT INDICATOR: 0.0218

Name	Normalized	Idealized
System cap.	0.23	0.54
Install. cost	0.23	0.54
Bank interest	0.12	0.29
ETS & Electricity	0.42	1.000

3. Financial Indicators

This study performs a financial analysis by comparison for a 10 MWp FPV investment in Agongdian Reservoir and Yamakura Dam and decides to invest in Japan or Taiwan by postulating that both sites are free of natural disasters during future operations. The FPV system uses the same primary components, like inverters and 315 Wp monocrystalline solar modules installed at Agondian Reservoir. It helps meet technological requirements and increase photoelectric conversion efficiency as the system has operated well since connecting the grid.

4. Miscellaneous Costs Assumptions

To quantify the two schemes' financial analysis, We assume:

1. The implementation of the FPV system is consistent with the 20 years.

2. The depreciation period of the FPV system is 25 years, regardless of the residual value [34].

Further, we set various parameters (based on annual income) as follows:

1. The module's yearly attenuation rate is 1% [27].
2. The annual operating cost and system maintenance costs are 3% in Taiwan and 5% in Japan (different salary levels between Taiwan and Japan) [35], [36].
3. The rent for the waters area of the two projects is 8.9% [15].
4. The capital investment ratio is 60% (Bank loan: 40% of the investment amount).
5. The interest rates of enterprise loans are 2.498% and 1.475% in Taiwan and Japan, respectively (April 2022) [37], [38].
6. The annual insurance expense is 0.5% of the FPV system's initial installation cost [39].
7. This study uses USD/NTD: 1: 29.5 and USD/JPY: 1: 126.4 for accounting since the US dollar against the Taiwan dollar has been between 27.6 and nearly 32 yuan, which is also close to the current rate. On the other hand, the USD/JPY has fluctuated too much, from close to 110 to 131 yen. Thus, we adopt 126.4 yen (the average value from January to April 2022) for the foundation [40], [41].

Items (1) to (4) are the same as that of the FPV Phase I of Agongdian Reservoir's annual operating revenue [15].

5. Financial Analyses

Investors can obtain the Concise Yearly Financial Statement based on the previous various cost assumptions and this subsection.

a. Operating Gain

It is not simple to predict the exchange rate of the Japanese yen or the Taiwan dollar against the US dollar, especially under the shadow of the epidemic spread, inflation, the Russian-Ukrainian war, and the Fed's hike to raise interest rates and shrink its balance sheet. By (15) and the average household electricity price in Taiwan (about US$0.11/kWh) [42] and Japan (US$0.24/kWh) [43]-[45], the annual operating gains are about US$ 1.3 and US$ 2.3 million, while the total operating gross profit for 25 years will be US$ 32.5 and US$ 57.5 million [34].

b. CO_2 Reduction Effect and Carbon Transaction

Based on the latest ECECs in Taiwan and Japan and Equation 16, the CO_2 emission reduction effect in the 25-year lifespan can reach approximately 143.6 and 120.2 kt, respectively. Due to the discrepancies in the national conditions of various countries, setting the ETS price needs to be equipped. This paper uses US$ 19 per ton, the same as Switzerland's, as the benchmark to obtain carbon credit benefits is about US$ 2.7 and US$ 2.3 million.

c. Installation Cost

The Climate Investment Funds (CIF) conducted a financial analysis for the 10 MWp FPV investment at Ramgiri (in Andhra Pradesh, India), which showed that FPV costs about US$ 1,000-1,200 per kW_p. However, costs are declining as China aggressively seeks larger installations, and other countries like Singapore and England follow it closely [46].

The National Renewable Energy Laboratory (NREL) lists US FPV-installed projects with project sizes greater than 100 kWp as of March 2021. Based on data provided by installers, FPV systems ranged in capacity from 1–100 MWp in 2020. Most existing FPV installations have powers below 5 MWp, but plans have more outstanding than 10 MWp since 2017. After comparing factors such as the site's specifics, the type of floating structure, the different anchoring solutions, and other factors that will affect system cost, it showed that the cost of a 10MWp FPV installation is US$ 1,290 per kWp in its technical report completed in October 2021 [47]. Based on this, the two systems' cost for Installation is US$ 12.9 million.

d. Capital Cost

We assume that WACC's α risk and the β risk parameters are 3% and 5.31%, respectively. Then, the WACC is 8.5% and 7.5% [48], and F_{crf} is 0.098 and 0.090. Accordingly, investigators can achieve annual loan capital costs of US$ 505.7 and US$ 464.4 thousand.

e. Taxes and PBP

Investigators can find the two plans' gross profits by subtracting the income items of a and b and the expenses of c and d. Regarding corporate income taxation, Japan has three tax items: corporate tax (national tax), prefectural inhabitant tax, and corporate business tax (the latter two are local taxes) [49], [50] At the same time, Taiwan has only a 20% corporate tax [51].

Japan's national tax adopts a progressive tax rate. The tax rate is 15% for the first 8 million yen (about US$ 63.3 thousand) of the profits and 23.2% for the portion over 8 million yen. Prefectural inhabitant tax is 1.8%, and corporate business tax is 1.0%. To sum up and summarize, the investor is only required to pay $600 in tax because its net profit before tax is only $3,000 for the Agongdian FPV; Yamakura FPV must pay about US$ 212.1 thousand in taxes yearly. The installer can achieve the project's PBP by adding depreciation to the after-tax earnings. The results show that the FPV invested in Taiwan's Agongdian Reservoir and Yamakura Dam must take about 25 years and 11.3 years to recover after grid connection.

f. Concise Yearly Financial Statement

Based on the above, list the two projects' concise statements in Table II.

g. Financial Indicators

In the post-FIT phase, funding in FPV in Japan is more favorable than in Taiwan as the current household electricity bill of the latter is about US$ 0.11 per kWh, which is much lower than that of most developed countries, resulting in almost nonprofit. By contrast, the former's financial indicators show that investing in FPV in Japan is more beneficial than in Taiwan due to the Yamakura Dam's modest IRR (11.6%) and BCR above 1 (2.0 at the discount rate, I = 10%) compared to the Agongdian Reservoir scheme's IRR (6.1) and BCR (1.3) at the same rate. Moreover, the NPV value at i = 10 of the Agongdian

Reservoir is negative (-3,623.8), while Yamakura's is positive (1,659.6) (Table III).

TABLE II
YEARLY CONCISE FINANCIAL STATEMENT

	Agongdian	Yamakura
Operating revenue (+)	1300.0	2300.0
Carbon credit (+)	109.1	91.4
Operational cost (-)	39.0	115.0
Maintenance cost (-)	39.0	115.0
Rent (-)	115.7	204.7
Depreciation cost (-)	516.0	516.0
Gross profit	699.4	1440.7
Gross profit (%)	53.8	62.6
Interest expense (-)	128.9	76.1
Insurance expense (-)	64.5	64.5
Capital cost (-)	505.7	464.4
Net profit before tax	0.3	835.7
Net profit after tax	0.24	623.6
Net profit (%)	0.02	26.1
Investment	12900	12900
Payback period	25	11.3

Unit: kUS$/Year

TABLE III
TABLE OF NPV, IRR, AND BCR

Discount Rate (i)	Agongdian	Yamakura
	NPV	
5%	1503.2	9,706.7
7%	-990.7	5,792.3
10%	-3,623.8	1,659.6
IRR (%)	6.1	11.6
BCR (i = 5%)	2.2	3.3
BCR (i = 7%)	1.7	2.6
BCR (i = 10%)	1.3	2.0

Unit: kUS$/Year

h. Breakeven Point

The breakeven point refers to the sales level at which the total revenue equals the total cost, i.e., the sales level where the profit is zero. Researchers commonly use it as an essential indicator in management accounting. Fig. 7 shows that the breakeven point of Yamakura FPV is about 61.3% [52]. It means that under the above conditions, when the power generation of Yamakura Reservoir FPV reaches 61.3%, the profit and loss equilibrium can be achieved. If power generation increases, it can be profitable. The Agongdian Reservoir FPV requires about 100% power generation to attain the balance point.

IV. DISCUSSION

Analyzing the metrics' logical tests and relative weights has shown that pricing electricity and ETS is critical to PBP. Although Taiwan imports about 97% of energy raw materials, the electricity bill is lower than most countries globally. It ascribes the government's long-term subsidies for fossil fuels. In contrast, it is more favorable to invest FPVs in Japan as its electricity price is higher than in Taiwan, although the former has higher labor and tax costs. In response to the high international fuel prices, Taiwan's government recently discussed raising the value and implementing it. It may help its FPV industry after the FIT stage [53].

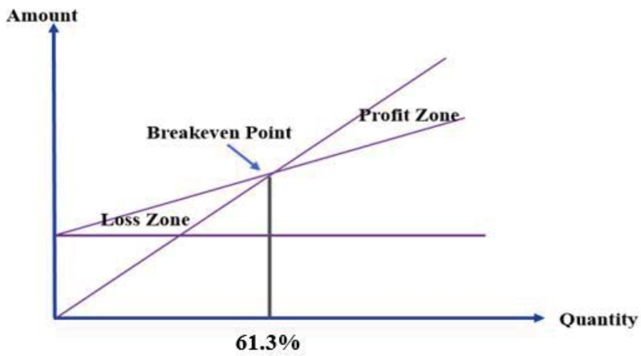

Fig. 7 Breakeven Point of Yamakura FPV

On the other hand, Taiwan's current household electricity price is approximately US$ 0.11 per kWh, which is much lower than that of most other countries, as mentioned above. With the prices of ETS and Electricity Bills rising with momentum, it can potentially launch Taiwan's FPV business in the future. Furthermore, it has only been five years since large-scale projects exceeding 5MWp were operated. FPVs need an excellent track record compared with grounded-based PVs. Their setting concerns environmental awareness, as protecting water resources from pollution is crucial. Though the material used for the floating body generally uses high-density polyethylene (HDPE), it has not caused accidents by degrading or polluting the water source. Installers must track it continuously and should first reserve the maintenance aisle for cleaning when installing solar modules. Maintaining and operating water-based panels requires clean water rather than detergents. In addition, the module's related components are susceptible to wind erosion, and the units are on the water's surface. They are easily affected by wind and moisture as the shaking of the device is also more likely to cause material fatigue. Thus, the installer should notice the structural requirements like wind, salt, and earthquake resistance. As a typical case of FPV security, the Yamakura FPV incident happened in September 2019 due to one of the strongest typhoons, Faxi, in 60 years, with a typhoon's impressive wind speed recorded at about 207 km per hour. It caused some parts of the system to be damaged. After the incident investigation, Japan's Ministry of Economy, Trade, and Industry (METI) concluded that the root causes were the island's size and shape, the stress concentration load, and the safety factors used during construction in April 2020. To avoid stress concentration, the designer has changed one floating island with a complex shape to a smaller island with a square shape, increasing safety factors [54].

All in all, avoiding biological water pollution and ensuring safe operation, like electrical parts on water, anchoring, and mooring, are critical for promoting the FPV business. The European Union (EU) will launch a carbon border adjustment mechanism (CBAM) and demand that companies disclose carbon emission data from October 2023 [55]. It is a proposed carbon tariff on carbon-intensive products (first impose cement, iron/steel, aluminum, fertilizer, and electricity). The EU importers must register with the member countries' authorities when importing them from overseas, declare the imported products' numbers and carbon emissions, and reflect their ETS to the EU for the previous year. Although committing to the carbon credit is obligatory, if the foreign exporters have paid the carbon prices in their countries, the EU will reduce the amount for them. According to the proposal, the reporting system will start as a preliminary stage in 2023, and the actual payment will be in 2026 [56]. According to Taiwan's Industry Bureau inventory, about 190,000 enterprises urgently demand to establish carbon reduction capabilities, and the first step is carbon inventory [57]. In Japan, the METI and the Ministry of the Environment are leading in introducing carbon pricing, including technical, financial, and institutional dimensions, to promote international cooperation toward global decarbonization and contribute to CBAM as a union with the EU [58]. As a result, the ETS will have upturn potential and contribute to the development of the FPV industry.

It is also worth mentioning that the installation cost in the first quarter of 2018, according to the NREL's survey, is about 30%-35% cheaper than in the past years. With the increase in FPV installation cases, the system's installation cost has a downward trend [59], [60]. Supported by the FPV robust industry's growth rate (exceeding 31% by 2024) under technological improvements and more carbon tariff levies [61], the business may be profitable to Taiwan.

Taiwan has 18 primary reservoirs. If we assume installers build them with the same module installation ratio, 0.067 (10,000 kWp/150,000 m^2), after estimating each reservoir's different sunshine conditions, the installed capacity will attain 2.18 GWp, yielding 7.26 GWh of daily power (20.74% of Taiwan's current peak power consumption, 35 GWh) [62]. It will reduce about 314 kt of CO_2 emission yearly for a 25-year lifespan [63] and save about 10.8 kt of water [64]. Compared to Japan, Taiwan's various reservoirs' water surface areas (natural, semi-natural, and artificial) are about 10,459.2 hectares [65], only approximately equivalent to 5.2% of Japan's total water surface area (about 202,465 hectares). Therefore, Japan's FPV development potential should be higher than Taiwan's, besides its higher electricity bills [66], [67]. However, Taiwan's 215.5 kt of CO_2 emission is better than Japan's approximately 180.2 kt in the FPV's 25-year life cycle, even though Japan's ECEC in 2020 is 0.538 kg CO_2e/kWh higher than Taiwan's 0.502 kg CO_2e/kWh in the same period. It implies that the FPV investors in Taiwan will attain a more handsome reward than the other side in the ETS of CO_2.

V. Conclusions

By serving the metrics' logical tests, we incorporated the weights of the factors into the comparative financial analysis, making the evaluation results objective. We assumed the various costs of analyzing and comparing the two schemes' economic indicators and performed the economic analyses using a holistic approach listed in section III *D*. The investigations found that the Yamakura FPV is more prominent as the NPV is more positive and extensive at the discount rate of 5%. Agongdian's IRR and BCR (at the rate of 10%) are about 6.1 and 1.3, inferior to Yamakura's 11.6% and 2.0. The latter's PBP is also better than the former. In addition, the bank interest is less significant in affecting the case profit. Investors may consider increasing the investment or loan ratio to create more returns.

As neither the investors of the original Agongdian nor Yamakura FPVs were public companies, as mentioned previously, the published financial information obtained could have been more considerable. Although this study benefits from selecting the optimal alternative, it is more complex to make a perfect assessment of all current and future costs and benefits, especially regarding environmental and risk-benefit analyses. We strongly recommend conducting further research on these topics in the future. The approach proposed in this paper provides systematic viewpoints to evaluate alternatives' pros and cons for identifying schemes. It benefits stakeholders in comprehending advantages and determining whether a decision is favorable while investing. It helps investors realize benefits while funding the project.

In summary, investing in FPV in Japan is more favorable than in Taiwan. In addition, the findings provide substantial evidence for the original assumption and show the rent cost significance. Moreover, as the bank loan interest rate is not the principal factor affecting the investment in FPV, increasing the loan ratio of the investment to expand the installation scale with the same capital should improve the profit.

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